

THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

VOL. 16

FEBRUARY, 1931

No. 2

IMMERSION LIQUIDS OF LOW REFRACTION

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Larsen¹ lists twenty-three minerals having indices lower than 1.45. Winchell² in his recent volume lists twenty-five in this range. Among these are such common minerals as opal, fluorite, and chrysocolla, as well as the familiar natron and cryolite. Forty-two optically known artificial inorganic substances³ also have indices below 1.45. All these substance have hitherto been excluded, for practical purposes, from those which can be easily identified by the immersion method, chiefly because all liquids of corresponding indices have certain properties which render their use difficult, if not impossible. Most of those listed⁴ have a solvent action on the crystals in question. This is particularly true of water, the alcohols, and their mixtures. Other liquids are known but these have such high vapor pressures that it is impossible to obtain reliably constant mixtures of any two to give intermediate values.

The writers have endeavored to fill the low index gap by fractionating and determining the optical properties of the lower petroleum distillates. Except for the lowest individual fractions, these liquids are ideal immersion media. They dissolve no known inorganic compounds; they may be obtained with almost any index without mixing; the index is constant on evaporation, and they are stable. The lowest members suffer the disadvantage of being very

¹ Esper S. Larsen, *The Microscopic Determination of the Nonopaque Minerals*, *U. S. G. S. Bulletin* 679, p. 163, 1921.

² N. H. Winchell and A. N. Winchell, *Elements of Optical Mineralogy*, Part III, 1929, p. 118 and p. 124.

³ Alexander N. Winchell, *The Optic and Microscopic Characters of Artificial Minerals*, *University of Wisconsin Studies in Science*, No. 4, p. 162, and pp. 168-9, 1927.

⁴ Albert Johannsen, *Manual of Petrographic Methods*, 1918, pp. 260-1. Esper S. Larsen, *op. cit.*, p. 15. Emile M. Chamot and Clyde W. Mason, *Handbook of Chemical Microscopy*, Vol. I, p. 386, 1930.

volatile, but even they have the very real advantage of not changing index appreciably on evaporation. They are no less accurate media than the upper members, but they allow the microscopist very little time to make observations before they have evaporated from the slide; there is the further attendant difficulty that their rapid evaporation lowers the temperature.

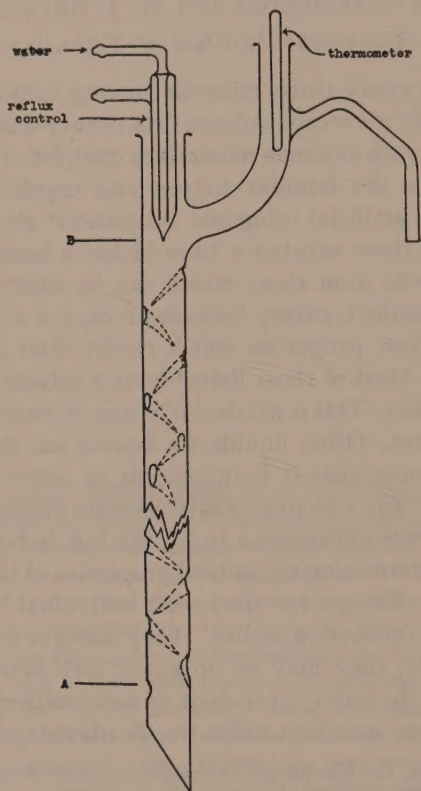


FIG. 1.

Several of the lower paraffins may be had on the market, but the number obtainable is insufficient to cover the desired range, and they can not be mixed to obtain intermediate liquids of lasting indices. For the purpose of immersion media, better liquids, although chemically less pure,⁵ are obtained by re-fractionating com-

⁵ This, while a fraction may have the boiling point of, say, nonane, it will not be composed of any single species of nonane nor indeed a mixture of nonane species,

mercial petroleum fractions, such as petroleum ether, the ligroins, gasoline, and kerosene. Fractions may be obtained between any desired boiling point limits, and if these be sufficiently narrow, the indices will change only very slightly on evaporation. The extent of these changes is indicated in Table IV; the first column giving the indices of representative liquids before evaporation, and the second, the indices after evaporation to one half the original volume in case this was possible, and if not, after air had been bubbled through them for eight hours.

In the writers' distillations two columns were used, both of the Vigreux type. A diagram of one is shown in Fig. 1. The larger was thirty inches from *A* to *B* and twenty millimeters inside diameter; the smaller, twenty inches from *A* to *B* and twenty-four millimeters inside diameter. The projections are not 90° apart but about 100°. This prevents the gases going directly up the perpendicular channels which would otherwise exist. It is necessary to exercise great care that each projection is so placed that the liquid dropping from its point will fall at the base of the second projection below; thus the fractionation is much better and the rate of distillation may be much more rapid without "choking." The reflux control must be supplied from a constant pressure device and the rate of flow of the water must be controlled by a needle valve. The water must, of course, be very nearly constant in temperature.

Five commercial distillates were used: petroleum ether, two ligroin's (Eastman's No. 513 and No. 1628), gasoline, and kerosene. All fractions obtained between 150° and 200° were redistilled once and all those below 150° twice. The limits are shown in Table II. The tables and graphs indicate concisely the results obtained.⁶

Table I indicates the relation between the boiling point and the volume of each fraction obtained on the first distillation, starting with a liter in each case. Under kerosene the second distillation is also listed. It is regretted that this information was not obtained for the whole series; however, that for kerosene will serve to indicate

but will be a complex mixture of hydrocarbons concerning the exact nature of which little is known. It is impossible to separate such a mixture into its pure components because of the great similarity of properties. For this reason it is an ideal immersion medium.

⁶ Due to the differences in commercial distillates produced at different times and by various manufacturers, the values given may be expected to differ somewhat in attempts at duplication. The values given will, however, serve as welcome guides when the preparation of a set of liquids of any desired range is required

TABLE I

VOLUME OF FRACTION ON FIRST DISTILLATION 1000 cc. USED IN EACH CASE					VOLUME OF FRACTION ON SECOND DISTILLA- TION OF KEROSENE	
Boiling point	Petroleum ether	Ligroin No. 513	Ligroin No. 1628	Gasolene		
20- 25	60					
25- 30	150					
30- 35	160					
35- 40	190			40		
40- 45	50			40		
45- 50	40			30		
50- 55	20			30		
55- 60	20			20		
60- 65	30			30		
65- 70	60			60		
70- 75	25	85		120		
75- 80	20	90		60		
80- 85	30	180		60		
85- 90		230	55	70		
90- 95	855	170	200	60		
95-100		85	270	60		
100-105		30	75	50		
105-110		10	50	40		
110-115			60	40		
115-120		880	50	30		
120-125			50	20		
125-130			45			
			855	860		
135-140					10	30
140-145					5	10
145-150					10	15
150-155					25	10
155-160					5	20
160-165					15	20
165-170					50	30

TABLE I (continued)

VOLUME OF FRACTION ON FIRST DISTILLATION 1000 cc. USED IN EACH CASE					VOLUME OF FRACTION ON SECOND DISTILLA- TION OF KEROSENE	
Boiling point	Petroleum ether	Ligroin No. 513	Ligroin No. 1628	Gasolene		
170-175					40	30
175-180					30	50
180-185					20	30
185-190					70	45
190-195					40	50
195-200					30	45
200-205					40	30
205-210					20	10
210-215					40	45
215-220					40	40
220-225					85	75
225-230					30	30
230-235					100	90
235-240					50	45
240-250					40	30
250-260					50	45
					845	825

what might be expected. Fig. 2 shows the values for kerosene graphically. Table II and Fig. 3 show the index at different temperatures for the final fractions. In Fig. 4 the index at 22°C is plotted against the upper boiling point limit. Whether the changes in slope are due to changes in equilibrium of the distilling column or to the constitution of the liquid we are not prepared to say, nor is it a matter of any importance to the work. Table III lists the dispersion, $n_F - n_C$, at 22°C for various indices.

TABLE II
INDEX OF REFRACTION AT DIFFERENT TEMPERATURES

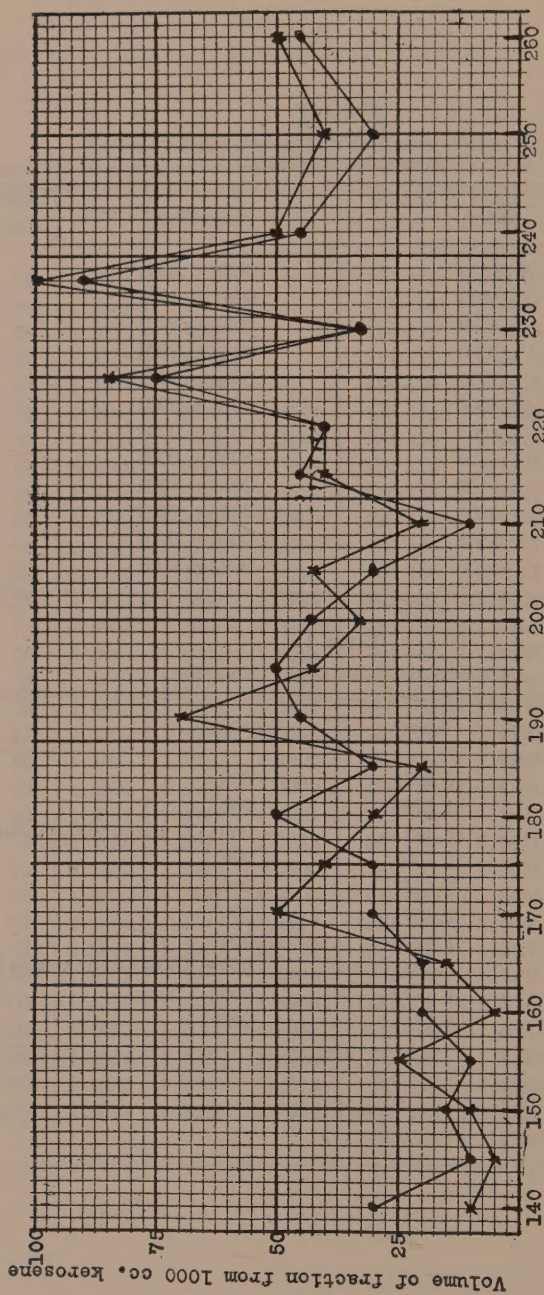
Boiling point	22°C	30°C	40°C	Boiling point	22°C	30°C	40°C
30- 32	1.3548			110-112	1.4074	1.4034	1.3983
32- 34	1.3562			112-114	1.4077	1.4038	1.3990
34- 35	1.3572	1.3521		114-116	1.4076	1.4037	1.3990
35- 37	1.3582	1.3533		116-118	1.4072	1.4032	1.3984
37- 40	1.3611	1.3562		118-120	1.4074	1.4038	1.3983
40- 42	1.3643	1.3593	1.3547	120-122	1.4080	1.4040	1.3993
54- 56	1.3739	1.3692	1.3642	122-124	1.4093	1.4052	1.4007
60- 62	1.3760	1.3716	1.3655	124-126	1.4108	1.4063	1.4018
62- 64	1.3776	1.3731	1.3672	126-128	1.4122	1.4080	1.4037
65- 67	1.3793	1.3750	1.3692	128-130	1.4146	1.4103	1.4059
67- 68	1.3838	1.3790	1.3737	130-135	1.4187	1.4145	1.4098
67- 70	1.3838	1.3790	1.3738	135-140	1.4212	1.4172	1.4128
70- 71	1.3889	1.3841	1.3788	140-145	1.4226	1.4188	1.4140
71- 72	1.3903	1.3857	1.3801	145-150	1.4241	1.4203	1.4157
74- 76	1.3967	1.3923	1.3868	150-155	1.4280	1.4241	1.4198
76- 78	1.3989	1.3945	1.3890	155-160	1.4308	1.4273	1.4224
78- 80	1.4013	1.3970	1.3915	160-165	1.4330	1.4293	1.4248
80- 82	1.4037	1.3991	1.3840	165-170	1.4349	1.4311	1.4268
86- 88	1.3993	1.3950	1.3899	170-175	1.4360	1.4323	1.4280
88- 90	1.3994	1.3953	1.3900	175-180	1.4381	1.4343	1.4300
90- 92	1.3991	1.3948	1.3897	180-185	1.4398	1.4360	1.4318
92- 94	1.3986	1.3946	1.3893	185-190	1.4411	1.4376	1.4330
94- 95	1.3992	1.3950	1.3900	190-195	1.4428	1.4393	1.4348
95- 96	1.4000	1.3957	1.3906	195-200	1.4444	1.4409	1.4368
96- 97	1.4008	1.3967	1.3917	200-210	1.4468	1.4433	1.4393
97- 98	1.4011	1.3870	1.3923	210-215	1.4479	1.4443	1.4400
98-100	1.4027	1.3983	1.3936	215-220	1.4491	1.4459	1.4417
100-102	1.4039	1.3998	1.3950	220-225	1.4500	1.4469	1.4424
102-104	1.4052	1.4011	1.3963	225-230	1.4520	1.4487	1.4443
104-106	1.4059	1.4021	1.3970	230-235	1.4530	1.4497	1.4453
106-108	1.4068	1.4030	1.3978	235-240	1.4550	1.4518	1.4473
108-110	1.4073	1.4034	1.3982	240-250	1.4569	1.4537	1.4495
				250-260	1.4593	1.4563	1.4518

TABLE III
DISPERSION AT 22°C

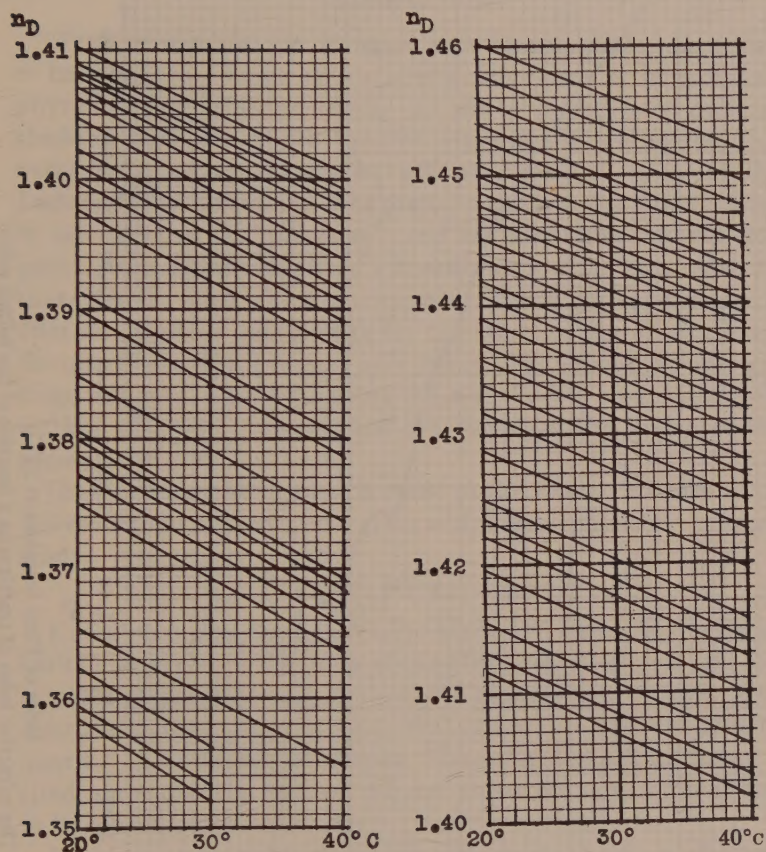
Index	Dispersion
1.3500	.0058 ± .0001
1.3600	.0062 ± .0001
1.3700	.0064 ± .0001
1.3800	.0068 ± .0001
1.3900	.0070 ± .0001
1.4000	.0073 ± .0001
1.4100	.0076 ± .0001
1.4200	.0080 ± .0001
1.4300	.0083 ± .0001
1.4400	.0086 ± .0001
1.4500	.0090 ± .0001
1.4600	.0092 ± .0001

TABLE IV
CHANGE OF INDEX ON EVAPORATION

Before	After	Change	
1.3562	1.3561	-.0001	} Evaporated to $\frac{1}{2}$ volume.
1.3776	1.3783	+.0007	
1.3838	1.3843	+.0005	
1.3991	1.3992	+.0001	
1.4059	1.4057	-.0002	} Air bubbled through for 8 hours.
1.4093	1.4091	-.0002	
1.4212	1.4210	-.0002	
1.4381	1.4381	.0000	
1.4479	1.4479	.0000	
1.4530	1.4530	.0000	

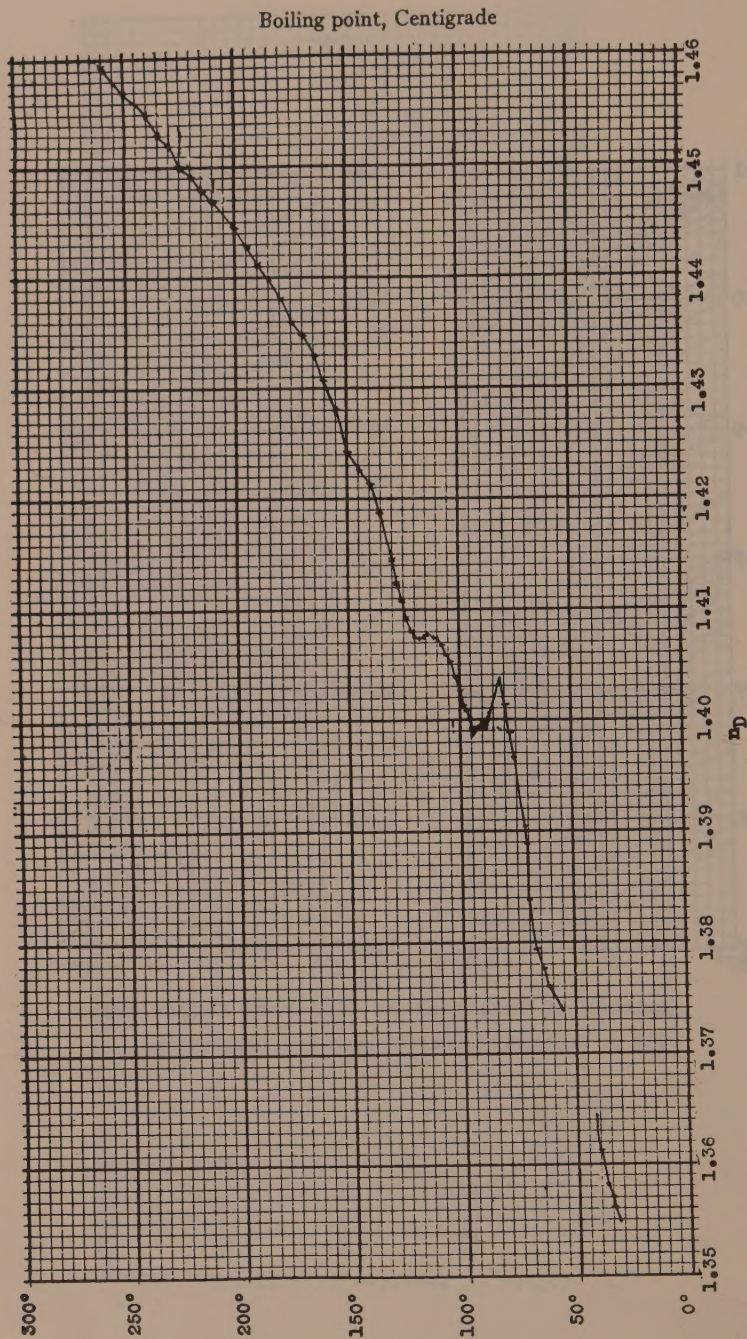


Boiling Point in C°.
 Fig. 2. Volume of fractions derived from one liter of kerosene at different temperatures.
 × first distillation
 • second distillation



Indices of fractions at different temperatures

FIG. 3. Variation of refractive index with temperature.



Index of Final Fractions at 22°C.

FIG. 4. The refractive index of fractions as a function of the boiling point.

"PRESSURE-SHADOWS" AND THE MEASUREMENT OF THE ORIENTATION OF MINERALS IN ROCKS

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INTRODUCTION

"Pressure-shadows" is the name sometimes applied to the fringes or halos differing from the groundmass that often accompany porphyroblasts in schistose rocks. Excellent examples of pressure-shadows were found with the pyrite porphyroblasts in the Calaveras formation and associated rocks at Carson Hill in the Mother Lode region of California. The pressure-shadows are always widest in the direction of "*Streckung*"¹ and are sometimes notably elongated. In the larger shadows it is easily seen with the unaided eye that they are filled with fibrous quartz. This occurrence seemed to offer an excellent opportunity for the study of the orientation of the quartz and of the factors affecting it. To this end the universal stage was used. In the following the material will be described, the method of study outlined, and the results of the measurements presented in graphical form.

Grateful acknowledgment is made to the Research Board of the University of California for a grant which made possible the present study.

PREVIOUS OBSERVATIONS

Knopf² has described "pressure-shadows" associated with ankerite and pyrite in the rocks of the Mother Lode region. He says in part, "Associated with some of the larger pyrite crystals is the quartz with the curious structure that causes it to be termed feather quartz." The microphotographs, Plates 8A and 8B, in the paper cited, show that the features referred to are the same as those here to be considered.

Moss³ has described in detail the geology of the area in which the

¹ The German word *Streckung* is used to designate the linear element in the plane of schistosity. The writer would be thankful for the suggestion of a suitable English word.

² Knopf, A., The Mother Lode System of California, *U. S. Geol. Surv., Prof. Paper* 157, pp. 41-42, 1929.

³ Moss, F. A., The Geology of the Mother Lode in the Vicinity of Carson Hill, Calaveras County, California, *Thesis, University of California*, 1927; also Moss, F. A., The Geology of Carson Hill, *Eng. and Mining Journal*, vol. 124, pp. 1010-1012, 1927.

materials for the present study were collected. He also observed the "pressure-shadows," but referred to them as "Streckungshoeefe," which he described both in the "Melones slate" (a member of the Calaveras formation) and in altered wall rocks.

FIELD OBSERVATIONS

Although the statements of Knopf indicate that similar materials are to be found elsewhere along the Mother Lode, the writer's observations are restricted to an area within several miles radius of Carson Hill. The rocks are largely those of the Calaveras formation and amphibolite schist.⁴ The Calaveras formation includes a great variety of metamorphosed rocks. For the most part they are slaty and in parts they are highly graphitic. The rock cleavage strikes uniformly NW and dips steeply to the NE. Even those rocks which did not lend themselves to the development of slates, such as conglomerates, show a marked schistosity and stretching. In the vicinity of the quartz veins and ore bodies, which in the main follow the regional strike, large masses occur, of altered rocks rich in carbonates and talc.

Pyrite, commonly associated with some of the gold ores, occurs sporadically in all of these rocks for several miles on either side of the highly mineralized belt. Sometimes the pyrite is fairly evenly distributed through the rock, or it may be in nests or stringers that may show a relation to a crack or a quartz veinlet and may parallel or transect the schistosity. Often the pyrite can be seen to be restricted to a zone in the rock from a few inches to several yards in width.

The pyrite varies from the most minute grains to cubes 4 or 5 mm. on an edge. The dominant form is the cube. The only other form observed, the pyritohedron, is quite subordinate. The usual striations are invariably present. No regularity in the orientation of the pyrite with respect to structures in the enclosing rock could be found. Occasional crystals are elongated or shortened parallel to one cube edge. Several large slabs of soft slate, from which the hard, perfectly coherent, limonite pseudomorphs after the pyrite could be easily removed, were brought into the laboratory. The number of cubes departing sufficiently from the ideal shape that they could be recognized without measurement was less than 1%.

⁴ For a geological map of the Mother Lode belt, see A. Knopf, *op. cit.* or *Folio*, 63, *Geol. Atlas of the U. S.*

This left such a small number of distorted crystals that it seemed hopeless to try to find any regularity in their orientation.

In the field pressure-shadows are often seen beside the pyrite, the limonite pseudomorphs, or the cavities left by the removal of these minerals. They are most easily seen where they are associated with the larger pyrite crystals and where they occur in the dark even-grained graphitic slates. It is also in these cases that they possess the greatest constancy of structure and composition, as will be described later. By megascopic observation only the larger shadows, which may equal or exceed the pyrite crystals in size, are discernible. These again are restricted to certain zones or patches within the areas bearing pyrite crystals. No obvious relation was found in the field between the distribution or frequency of occurrence of the pressure shadows and features of the enclosing rocks, but the microscopic study yielded some suggestions.

Quartz is the only constituent of the shadows that can be surely recognized in the field. Nevertheless, the cellular character of the shadows in some places and their entire removal in others indicate the former presence of other minerals.

MICROSCOPIC DESCRIPTION

Specimens of various rock types bearing pyrite porphyroblasts from a dozen different points near Carson Hill were studied microscopically. Pressure shadows were found in all, though the character of these varies greatly with the size of the pyrite crystals and the nature of the enclosing rock. There is great constancy in the character of the shadows from any one locality. Where the average size of the shadows is small they may be entirely lacking from some of the pyrite crystals.

The pressure shadows are invariably extended in the direction of the schistosity. They appear on one or both ends of the pyrite crystals and not infrequently narrow fringes entirely surround the pyrite. The shape of the shadows is largely dependent upon the orientation of the porphyroblasts with respect to the schistosity. If a cube face is perpendicular to the schistosity the shadows are generally rectangular in cross-section. Where the cube faces are oblique to the schistosity the shadows are often wedge-shaped, as shown in Fig. 1.

For the most part the shadows are exceedingly regular in structure and are bounded by plane surfaces. Such shadows though

they vary in width, are rarely if ever wider than the pyrite crystals to which they are attached and mostly they are much narrower. From a single locality, the dump of the Tulloch Mine, specimens of shadows of an entirely different sort were obtained. Here the rock



FIG. 1. Wedge-shaped "pressure-shadows" of feather quartz surrounding pyrite. Some chlorite in outer part of shadows. Crossed nicols. $\times 12$.



FIG. 2. Distorted "pressure-shadow" with feather quartz in various orientations. Crossed nicols. $\times 11$.

is a crumbling graphitic slate. The shadows are usually very much larger than the pyrite about which they occur. They are irregular in shape, heterogeneous in structure and composition and much elongated in the direction of schistosity as is shown in Fig. 2. Some of these, at least, seem to have formed while the matrix was

undergoing movement so that several stages in their formation may be recognized. They will not be further considered here as they seem to be dependent on local conditions and to differ sharply from the more typical shadows.

The minerals of the pressure-shadows, in order of frequency of occurrence are: quartz, chlorite (probably penninite), carbonates (calcite or ankerite) and sericite (talc?). A particular shadow may contain any one or any group of these.



FIG. 3

Fringes of quartz around pyrite in slate.
Crossed nicols. $\times 11$.

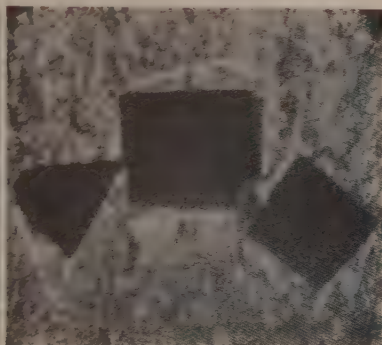


FIG. 4

"Shadows" of chlorite and sericite adjoining pyrite. Crossed nicols. $\times 11$.

The shadows are best developed in the smooth graphitic slates of the Calaveras formation. They consist of feather quartz with minor amounts of the other constituents as shown in Figs. 1, 5, and 6. They are entirely free from any remnants of the matrix. The quartz is invariably oriented with the axes of elongation of the grains normal to the pyrite face on which the shadow occurs, even in those parts where the feather quartz is not in contact with the pyrite. Most frequently the minor minerals lie in the outer part of the shadow. If granular quartz is present it likewise tends to lie at the outer edge of the shadow giving way to feather quartz near the pyrite. A few shadows contain coarser and finer feather quartz. In these cases the coarser quartz is usually toward the inside. Exceptions to these more common arrangements of the constituents in the shadows are rare.

In some other rocks, as the quartz-carbonate or talc-carbonate rocks in the highly mineralized zones, chlorite, sericite or carbon-

ates may be the chief minerals in the shadows, sometimes with narrow fringes of feather quartz as shown in Fig. 4. In the case of small pyrite crystals a shadow may consist of a single crystal of sericite or chlorite with the basal plane parallel to the pyrite face.

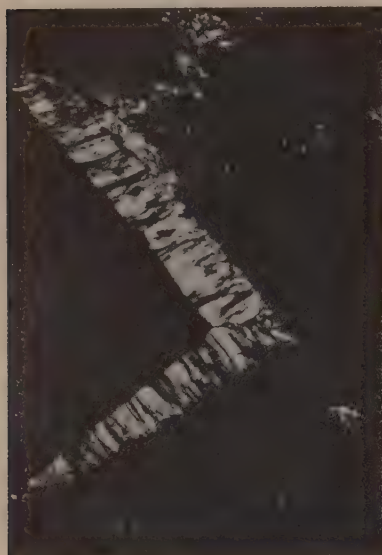


FIG. 5

Detail of two pressure-shadows showing structure of feather quartz. Crossed nicols. $\times 12$.

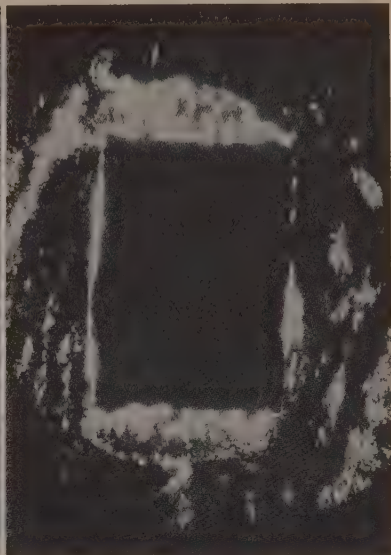


FIG. 6

Pressure-shadows showing granular quartz and chlorite in outer part and feather quartz in inner part. Crossed nicols. $\times 14$.

METHOD OF MEASUREMENT

The orientation of the long dimensions of the quartz grains normal to the controlling pyrite face is so striking and so constant that it hardly requires measurement. The question arises whether there is any constant relation between the elongation of the grains and the crystal lattice. To answer this it is necessary to obtain data as to the orientation of some crystallographical direction of the quartz with respect to some system of reference.

These data are obtainable by measurement of the orientation of the optical ellipsoid under the microscope. This may be carried out by measurement of the azimuths of the projections of the optic

axes for uniaxial minerals and may be amplified by repetition on thin sections cut in three planes at right angles.⁵ The use of the universal stage permits a more complete measurement and seems especially adapted to the present case.

The study of the orientation of minerals in rocks has been carried on most diligently for sometime by Sander and Schmidt and their students and reference should be made to their writings for an exhaustive discussion of the many problems involved. More recently Schmidt⁶ has introduced the method of the universal stage to these studies and has given a convenient method of representing the results. In this discussion the method and the conventions of Professor Schmidt will be followed closely and reference can be made to the paper cited for points not covered here.

The work was done with a Leitz Universal Stage mounted on a Leitz petrographic microscope fitted with an arresting clamp under the microscope stage. Because of the fine grain of some of the material measured a 24 mm. microsummar objective was used, since this gives the maximum magnification combined with sufficient clearance above the stage. It was only possible to work with bright illumination since it was necessary to stop down both the objective and sub-stage diaphragms to small openings. In addition a guiding-sledge (after W. Schmidt as furnished by E. Leitz, Wetzlar) was used and attached to the mounting of the upper hemisphere of the universal stage. This attachment allows the thin section to be moved between the hemispheres without loss of orientation and is essential to all such measurements as those here reported.

Under the universal stage it is easy to establish the direction of the optic axis of a uniaxial mineral. If the horizontal projection of the optic axis is brought to coincidence with the direction of the A_4 axis⁷ by turning on the A_1 axis and the section inclined by rotating on the A_4 axis, the mineral will (unless its optic axis lies in the plane of the section) be turned out of the extinction position. If the

⁵ G. Fischer, Gefuegeregelung und Granittektonik, *Neues Jahrb., Beil. Band, Abt. B*, vol. 54, pp. 95-114, 1926.

⁶ Schmidt, W., Gefuegestatistik, *Tschermak's Mitt.*, vol. 38, pp. 392-423, 1925.

⁷ For a general description of the use of the universal stage see M. Berek, *Mikroskopische Mineralbestimmung mit Hilfe der Universaldrehtischmethoden*, Berlin, 1924; for a brief account A. N. Winchell, *Elements of Optical Mineralogy*, Part I, 3rd. Ed., 1928. Of the three cases there mentioned on page 225, only the first two are possible in uniaxial minerals, the second being the general case.

section is now tilted by rotation of the A_2 axis to re-establish extinction and A_4 turned back to zero, one of two positions will have been reached; the optic axis now coincides with either A_4 (equatorial position) or A_6 (polar position). This is determined by rotating on A_6 . If the mineral is in the polar position it remains at extinction; if it is in the equatorial position it shows maximum interference colors. Those grains whose optic axes lie near 45° to the plane of the section may be read from both positions.⁸

Thus are obtained two values for each grain examined, the readings on A_1 and A_2 for one or another of the two positions. These values may be thought of as defining points on a sphere and as each defines two points at opposite ends of a diameter it is necessary to make an arbitrary decision as to which is to be used. Following Schmidt we will use the lower hemisphere.

This hemisphere is now projected onto the equatorial plane by an equal-area projection, necessitated by the statistical purpose and differing from a stereographic projection in that polar distances are plotted after the equation, $r = 2a \sin \phi/2$, from the center. In practice the readings are plotted directly on the projection. The readings on A_1 give the azimuths. For equatorial positions the readings on A_2 are plotted in from the circumference and for polar positions they are plotted out from the center, care being taken in every case to note whether the stage was tilted to the right or to the left. By thus plotting all observations a series of points is obtained as shown in Fig. 9 which show the distribution of the c axes of the measured grains.⁹

It has been customary in the work of Schmidt and others that this projection be subjected to further graphical treatment. The percentage of the total number of plotted points falling within 1% of the area of the projection is measured by running a square having 1% of the area of the projection over it and counting the number of points in the square which, divided by the number of

⁸ Note that A_3 is not used in dealing with uniaxial minerals and is conveniently kept clamped at 270° during these measurements.

⁹ It should be noted that this still allows an infinite number of orientations to each grain as the several directions normal to the optic axis of a uniaxial mineral cannot be distinguished by optical means. In the case of biaxial minerals each grain must be represented by two points corresponding to some chosen two axes of the triaxial ellipsoid. This completely defines the orientation of the crystal lattice if the optical orientation be known and constant. The writer hopes soon to present examples of the measurement of biaxial minerals.

grains measured gives the percentage density of distribution over the projection.¹⁰ Contour lines may then be drawn according to some arbitrary scheme and the areas shaded between the several contours. In this way Fig. 10 was obtained from Fig. 9.

The accuracy of such a representation depends upon the degree of orientation of the crystals and upon the number measured. Where the orientation is complex or poor the measurement of several hundred is desirable. It also must be emphasized that lack of orientation combined with a limited number of measurements unavoidably leads to the appearance of a patchy distribution. Very many measurements would be required to give a uniform distribution of points over the entire projection.

A limit to the shadows or the grains that can be used for orientation measurements is set by the size of the grains. With favorable orientation of the boundaries and of *c* axes the smallest grains distinguishable by the observer are susceptible to measurement, but it is always necessary that in the final position of the stage the grain under observation shall show a visible breadth that does not overlap with other grains vertically, otherwise the proper extinction position cannot be recognized. In general the diameter of a grain in random attitude and with boundaries normal to the plane of the section must be more than double the thickness of the section.

Other data may be entered in the projection to show the system of reference. If oriented material has been collected and due care taken in the marking of specimens, cutting and mounting of sections, measuring and recording, it will be possible to show north, east, direction of schistosity or any other known direction in the orientation diagram. This is useful in the application of such measurements to structural problems, especially in schistose rocks.

RESULTS OF THE MEASUREMENTS

The material collected for the present study was in part oriented in the field, but since the attitude of the schistosity is uniform throughout and since the purpose of the work has no connection with structural relations the field orientation need not be considered in the diagrams here presented.

The largest number of measurable quartz grains found in a single

¹⁰ A transparent square grid may also be used for this purpose. Where the number of points is small it is best to count them within some larger unit, say 2 or 4 per cent of the area.

shadow was 81. This number is smaller than would have been desirable. The orientation diagram obtained for this shadow is shown in Fig. 7. The patchy pattern does not disclose any simple

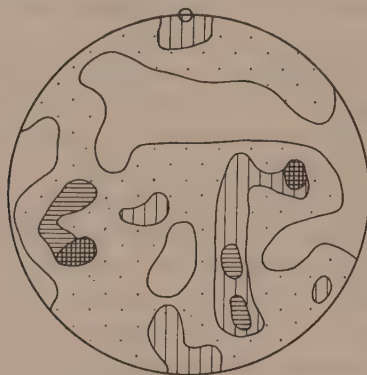


FIG. 7. Orientation diagram for 81 quartz grains in one "pressure shadow." Small circle indicates pole of pyrite face.

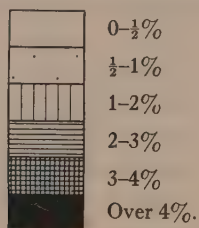


FIG. 8. Orientation diagram for 145 quartz grains in several shadows in the same thin-section. The plane of projection is the plane of rock cleavage. The small circle designates the pole of the *Streckung*.

orientation and may be the result of a limited number of measurements in an unoriented aggregate. All other single shadows measured show a similar lack of orientation but lend themselves even less to statistical treatment because of the smaller number of grains.

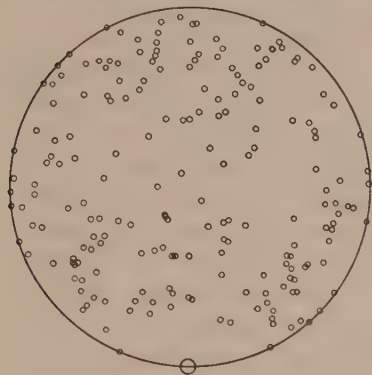


FIG. 9

Poles of the optic axes of 193 quartz grains in 7 "pressure-shadows" all referred to the poles of the pyrite faces involved. Small circle at bottom indicates pole of pyrite faces.

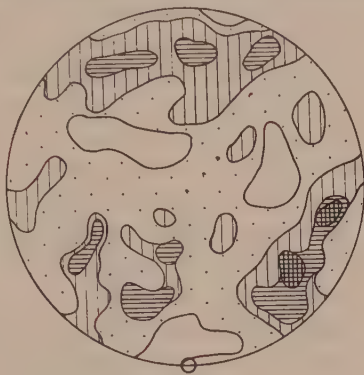


FIG. 10

Composite orientation diagram for 193 quartz grains in 7 "pressure-shadows" all referred to the poles of the pyrite faces involved. Small circle indicates pole of pyrite faces.



FIG. 11

Representation of the azimuth measurements from FIG. 9. The centrosymmetry of such diagrams is without significance as to the orientation of the material. The circle represents uniform distribution of the same number of azimuths. The broken line indicates the azimuth of the pyrite faces.

To obtain a larger number of points on one diagram all the measurements from the shadows in one thin section were combined for the orientation diagram shown in Fig. 8. The plane of the projec-

tion is the plane of rock-cleavage and the direction of the *Streckung* is, of course, the same for all the shadows. Again the pattern is a patchy one and shows no dependence on the direction of the *Streckung*.

Fischer¹¹ has combined similar measurements from a large number of shadows by referring all the measurements to the faces of the porphyroblasts. The same procedure has been followed in making Figs. 9, 10 and 11. Fig. 9 shows the poles of all the quartz grains measured in seven shadows attached to pyrite faces of accurately known attitude so that they could be combined by reorienting the original projections to bring the pyrite faces into coincidence. Fig. 10 shows the orientation diagram for the same material. It shows the same patchy pattern as Figs. 7 and 8. For those who are more accustomed to the older type of orientation diagram the azimuths alone from the measurements for Fig. 9 are plotted in Fig. 11. This gives the sort of a diagram that would have been obtained had the projections of the optic axes been measured without the use of the universal stage.¹²

All these orientation diagrams show the irregular pattern which Schmidt¹³ says is typical of unoriented or poorly oriented material. This lack of orientation is most surprising in view of the constancy in character of the feather quartz. It is also in conflict with the conclusion drawn by Fischer that the *c* axes of the quartz grains tend to be oriented normal to the controlling crystal face, though he states that this orientation is rather imperfect.¹⁴ If the orientation of the quartz in the present case were as he suggests there should be maxima at the top (and bottom) and minima bands across the center in Figs. 7 and 10. Certainly no such arrangement can be seen.

The suspicion arises that the comparatively small number of measurements is insufficient to show the arrangement.¹⁵ To check this 100 quartz grains were measured in a thin section of "meso alkali-feldspar gneiss," Chemnitz, Saxony, from the "Grubenmann collection" of the University of California. The results are shown in

¹¹ *Op. cit.*, p. 112. Fischer did not use the universal stage.

¹² Fig. 11 is comparable to Fischer's Fig. 30.

¹³ See the similar patterns in the paper cited.

¹⁴ See especially Fischer's Fig. 31 in the paper cited.

¹⁵ Though Schmidt has published orientation diagrams based on less than 50 grains. See W. Schmidt, Zur Regelung zweiaxiger Mineralien in kristallinen Schiefen, *Neues Jahrb., Beilb.* 57 A, pp. 203-222, 1928.

Figs. 12, 13 and 14, which should be compared with Figs. 9, 10 and 11. It is seen that in the case of good orientation the measurement of even 100 grains is ample to bring out the arrangement very

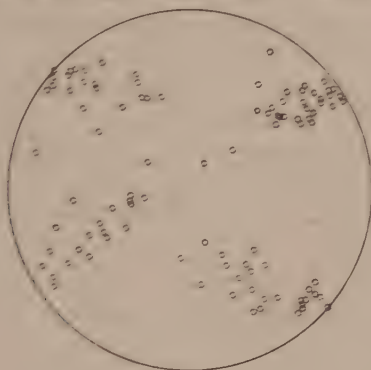


FIG. 12

Poles of the optic axes of 100 quartz grains in "meso alkali-feldspar gneiss" from Chemnitz, Saxony.

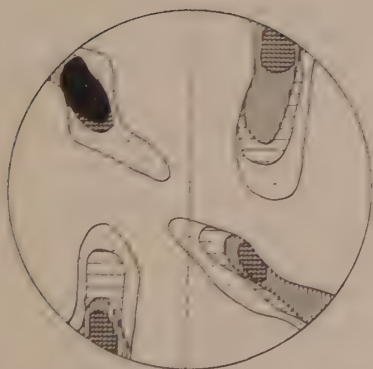


FIG. 13

Orientation diagram for 100 quartz grains in "meso alkali-feldspar gneiss" from Chemnitz, Saxony. The dashed line indicates trace of schistosity in the thin-section.

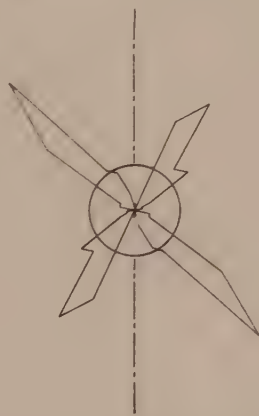


FIG. 14

Representation of the azimuth measurements from Fig. 12. Broken line indicates trace of schistosity in thin section. Contrast with Fig. 11.

clearly in a diagram. Moreover the minima are entirely clear and after the measurement of but 25 grains the result was easily to be foreseen. In addition a comparison of Figs. 13 and 14 shows

the superiority of measurement on the universal stage and representation in the equal area projection over the old methods. Two continuous diagonal bands or just two patches, say at the upper right and lower right sides of the projection in Fig. 13, would have the same appearance as Fig. 14 in the purely azimuthal projection.

Certain statements as to the orientation of the quartz in these pressure shadows now seem justified:

1. Where definite feather quartz is developed the long axes of the grains are at right angles to the controlling pyrite face whatever its attitude with respect to the schistosity of the enclosing rock. This is in harmony with the observations of others.

2. The measurements here reported do not indicate that there is a tendency for any crystallographic direction of the quartz to parallel the elongation of the grains.

This conclusion conflicts with that of Fischer who thought he recognized a tendency for the *c* axes of the quartz to assume a position normal to the controlling crystal face.¹⁶ Still the diagrams he presents show no pronounced maxima and it seems that they may be merely the equivalents of such patchy patterns as are shown in Figs. 7 and 10. In any event it is certain that the orientation of the quartz crystals is very poor at best. It is, for instance, not nearly so good as the orientation of the constituents in a granitic rock showing only a very moderate flow structure.¹⁷

In a very few cases carbonates were found filling a shadow with elongated grains similar to feather quartz. They show the same lack of orientation. Enough measurements were not carried out to warrant their publication.

ORIGIN OF THE FEATHER QUARTZ

Before the origin of the pressure-shadows can be taken up it is necessary to consider the relation of the pyrite crystals to the slate. Knopf says,¹⁸ "Metasomatic pyrite is common in sharp crystals, which invariably transect the cleavage of the slate—a feature that points to the relatively late introduction of the pyrite, after the flowage of the slate had ceased." He makes no statement as to the

¹⁶ In Fischer's case magnetite crystals. *Op. cit.*, p. 111.

¹⁷ Compare, for example, A. Pabst, Observations on Inclusions in the Granitic Rocks of the Sierra Nevada, *Univ. Calif. Publ. Bull., Dept. Geol.*, vol. 17, pp. 325–386, 1928, Fig. 7.

¹⁸ *Op. cit.*, p. 42.

origin of the pressure-shadows filled with feather quartz, but, as they are quite different from the pressure-shadows formed by replacement in association with "augen" of carbonates, it seems that they require a different explanation.

The lack of inclusions of matrix in the pressure-shadows, their sharp boundaries, their extension in the direction of the *Streckung*, and the evident movement of the enclosing slate about them in some cases lends plausibility to the assumption that they are the result of extension in the slate in the plane of schistosity which tended to pull the matrix from the sides of the pyrite porphyroblasts, the potential opening being filled continuously with quartz. Professor Mügge has given a description of similar material and has elucidated the formation of such shadows (*Streckungshöfe*) with the aid of schematic drawings.¹⁹ The filling of such potential openings with new mineral matter is easily explained by Riecke's principle.²⁰

Mügge also gives an explanation of the origin of feather quartz which fits the results here obtained.²¹ If quartz seeds begin to grow at the boundary of the slate which tends to be pulled away from the porphyroblast, they will grow in all directions until they hinder each other laterally. Then they will continue to grow inwards into the potential opening at rates depending on the orientation of the several grains. Mügge distinguishes three cases:

1. If the rate at which the space is being opened²² is greater than the maximum growth rate of the quartz grains an empty space will form in front of them. Then new nuclei may start in this space or, failing this, the grains with axes of most rapid growth normal to the surface of the aggregate will suppress the other grains. A fibrous aggregate normal to the surface from which growth occurs and with a measure of crystallographical orientation would result.

¹⁹ Mügge, O., Ueber die Entstehung faseriger Minerale und ihrer Aggregationsformen, *Neues Jahrb., Beilb. 58 A*, pp. 303-348, 1928.

²⁰ Schwinner, R., Kristallisation unter gerichtetem Druck, *Tschermak's Mitt.*, vol. 37, pp. 219-235, 1926. S. points out that Riecke's principle is often misinterpreted but that it does state that the solubility of an unstressed crystal is lower than that of a stressed crystal, other things being equal. This allows the migration of matter in rocks under stress to points sheltered from stress as, for instance, pressure-shadows.

²¹ *Op. cit.*, pp. 308-315.

²² That component of the rate of movement of the slate *normal* to the pyrite face in question may be taken as the rate of opening.

2. If the rate of opening of the crevice is between the maximum and minimum growth rates of the grains, the slow grains are again suppressed but the faster grains remain in contact with the opposite surface and hindering each other laterally will form a fibrous aggregate normal to the opposite surface and with some measure of crystallographical orientation.

3. If the rate of opening of the crevice is less than the minimum growth rate of the grains, all remain in contact with the opposite side and have an equal chance. Then a fibrous aggregate results with the fibres normal to the opposite side but without crystallographical orientation.

If such a scheme is acceptable it appears that the third case is realized in the material examined.

CRYSTAL STRUCTURE OF THE SERIES OF BARIUM AND STRONTIUM CARBONATES*

J. M. CORK AND S. L. GERHARD, *University of Michigan.*

ABSTRACT

Using the powder method a study was made of the effect upon the lattice constants of barium carbonate by the addition of definite molecular fractions of strontium carbonate. The mixtures examined were of two kinds: (a) mechanical and (b) precipitated. In the former case each component shows its own definite pattern while in the latter only a single intermediate pattern is observed obeying approximately the additive law of Vegard. The effect of heating the pure and mixed carbonates during x-ray exposures was investigated. Spectrometer measurements upon natural witherite crystals together with powder pattern measurements on barium carbonate indicate that the previously reported dimensions of the unit orthorhombic cell must be somewhat modified.

The extensive use of various forms of alkaline earth compounds on surfaces employed in electron emission makes any information regarding their crystal structure of interest.

Speculation regarding the lattice constants of barium and strontium carbonates as well as of other carbonates possessing the aragonite type of structure was carried out by Huggins.¹ His results were based upon the axial ratio values given by Groth, together with the value of the density and the assumption that there were two molecules associated with each unit orthorhombic cell.

From measurements of diffraction patterns, using the powdered crystal method, Wilson² reported values of the lattice constants quite different from those recorded by Huggins. These were based upon a unit orthorhombic cell containing four molecules, and a space group assignment of $2D_4-16 (Q_k^{16})$ as found by Wyckoff³ for the related mineral aragonite.

In the present investigation the object was three-fold: (a) to determine as precisely as possible the dimensions of the unit cell of the primary substance, barium carbonate; (b) to show how this is modified by the addition of another constituent, strontium carbonate, in varying amounts, (c) to observe any difference when the added constituent is introduced by different methods.

* This investigation was undertaken at the request and with the financial assistance of the Grigsby-Grunow Co., Chicago, Ill.

¹ M. Huggins, *Phys. Rev.*, **19**, p. 354, 1922.

² T. A. Wilson, *Phys. Rev.*, **31**, p. 305, 1928.

³ R. W. C. Wyckoff, *Amer. Jour. of Scien.*, vol. 9, p. 145.

POWDER METHOD

Using the Hull-Debye-Scherrer method employing molybdenum K_{α} x -radiation, diffraction patterns were obtained for mixtures of barium and strontium carbonates of varying compositions. These mixtures were of two kinds: (a) mechanical, produced by mixing pure barium carbonate and pure strontium carbonate in the desired proportions, and (b) precipitated, formed either by passing carbon dioxide into a solution containing definite parts by weight of strontium and barium hydroxides, or by adding sodium carbonate to a solution of strontium and barium nitrates in the desired proportions.

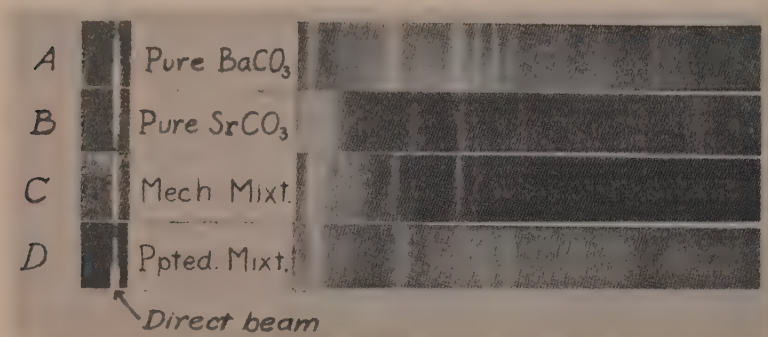


FIG. 1.

The following three types of mountings were employed for the samples under investigation: (a) thin-walled glass capillary tubes, (b) coating on thin nickel wires, (c) thin sheet behind an added fine brass slit. In every case the specimen was mixed with some other crystalline substance such as potassium chloride, sodium chloride, or nickel oxide, in order to have known reference lines in measuring the films.

Typical diffraction patterns obtained for the pure barium and strontium carbonates are shown in A and B, Fig. 1. It is readily observed that the patterns are of the same nature except that the $SrCO_3$ pattern is displaced more toward larger angles from the direct beam than the $BaCO_3$ pattern, because of the smaller dimensions of the unit orthorhombic cell for strontium carbonate.

C and D in Fig. 1 illustrate the result obtained with mechanical and precipitated mixtures of equal amounts of barium and stron-

tium carbonates. In the former case both barium and strontium patterns are clearly present while in the latter case only a single intermediate pattern is observed. Single definite patterns of this sort were observed for every precipitated mixture, its position with

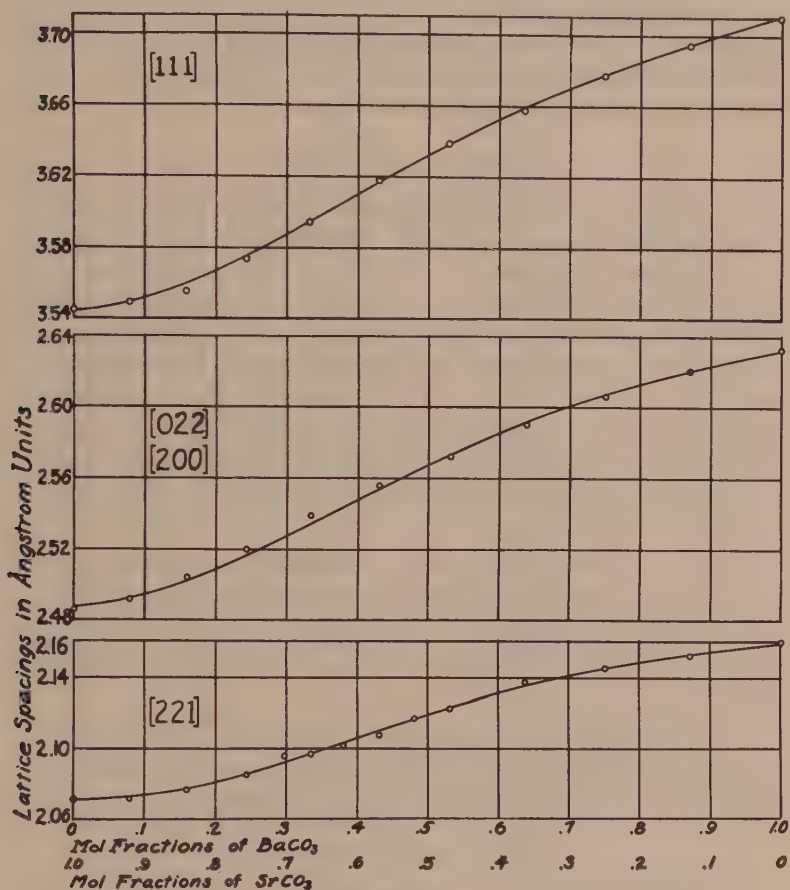


FIG. 2.

respect to the parent patterns being determined solely by the molecular fractions of the components present. This shows clearly that the metallic barium atoms in the carbonate lattice are replaceable by strontium atoms with a slight accompanying decrease in lattice dimensions or vice versa.

The variation in the lattice dimensions with varying molecular fractions of constituents is shown in Fig. 2 for a few of the principal

lines in the diffraction patterns. These lines for the precipitated mixtures are in general as sharp as those for the pure substances. It is remarkable that a replacement of one atom of every one hundred barium atoms in the barium carbonate structure by a strontium atom should produce a general contraction of the whole lattice with no loss of definiteness in the diffracted line. The curves of Fig. 2 differ from straight lines only at each end, thus exhibiting a slight deviation from the 'additive' law of Vegard.⁴

TEMPERATURE EFFECT

The effect of heating the mixtures on nickel wires during the x -ray exposure was investigated. Specimens of the precipitated type containing equal parts of strontium and barium carbonates, as well as others of the pure substances were investigated in this way. Each was maintained during the exposure at a constant high temperature perhaps slightly above 1000°C . While this heating was carried out in the presence of air and would be thereby somewhat affected, it is quite probable that the major changes so observed would represent those occurring in the activation of the filaments of radio tubes. Certain results of these tests may be summarized as follows:

- (a) In pure barium carbonate no change in structure occurred but simply an enlargement of the lattice by temperature expansion.
- (b) In pure strontium carbonate a definite transformation took place in which the strontium carbonate changed into strontium oxide.
- (c) In the precipitated mixture of equal parts, diffraction patterns were observed of lines whose origin was not determined, besides those of barium carbonate, strontium oxide and nickel oxide.

SPECTROMETER METHOD

To evaluate precisely the lattice constants of a crystal, the powder method is hardly satisfactory. When large single crystals are obtainable the spectrometer yields results of much greater precision.

Natural barium carbonate crystals known as witherite are readily obtained. As the result of twinning these crystals are pseudo-hexagonal in form. The pyramidal faces have the Miller indices $\{111\}$ and give nearly perfect x -ray reflections.

⁴ Vegard, *Zeit. für Krist.*, **67**, p. 239, 1928.

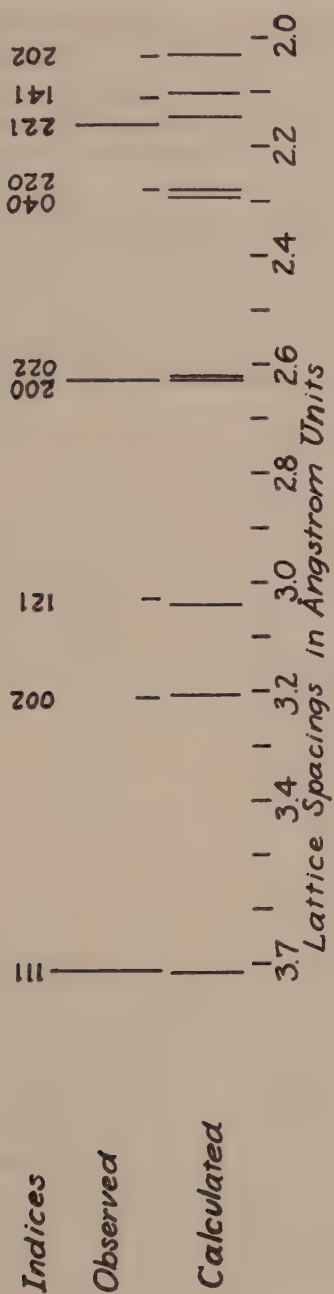


FIG. 3.

Using a Siegbahn vacuum spectrograph with copper K radiation a determination of the interplanar distance for this face was carried out. In this investigation the method employed in precision wave-length measurement was used, that is, crystal and plate were each rotated so as to give on the same plate in almost coincident positions the lines taken on each side of the direct beam. Using the Siegbahn values for the wave-lengths of the copper lines, a value for d_{111} of 3.7178 Ångstroms was obtained.

TABLE I

Plane Set	Wilson's Values	Observed Powder Lines	Present Values
100	5.252	—	5.256
010	8.828	—	9.172
001	6.544	—	6.412
—	—	—	—
111	3.717	3.71	3.717 ^a
002	3.272	3.21	3.206
121	3.003	3.03	3.040
022	2.629	2.63	2.627
200	2.626		2.628
220	2.257	2.28	2.280
040	2.207		2.293
221	2.134	2.16	2.149
141	1.942	2.11	2.102
202	2.084	2.03 ^b	2.033
Volume of Unit Cell	303.4		309.1
Density	4.320		4.245

The axial ratio for barium carbonate given by Growth is: $a:b:c = 0.5949:1:0.7413$. This axial ratio together with the above measurement on the {111} face would demand the following values for the edges of the unit orthorhombic cell: 5.2556, 8.8345, and 6.5490 ÅU. The dimensions of the unit cell given by Wilson were: 5.252, 8.828, and 6.544 Å.U., in excellent agreement with the above. Now, while these values satisfy the Groth ratio and give the observed {111} spacing, it is still not possible by using them to obtain an agreement between the calculated values for other principal spacings and observed lines in the powder diffraction pattern. While as mentioned above the powder method is incapable of yield-

ing the utmost accuracy, still it should not differ from the true values by more than one, or at most two, hundredths of an Ångstrom unit. Table 1 shows the observed values of the first eight principal lines, together with the values as calculated from the above lattice constants. The discrepancy is too great to be permissible.

In order to check this further spectrometer measurements were made upon the $\{001\}$ plane. This plane was obtained from a natural crystal by grinding it normal to the c -axis in which case the three components of the trilling act together. Spectrometer measurements on this set of planes gave a value 6.412 Å.U. , which would yield very satisfactorily the second line in the diffraction pattern, namely 3.21 Ångstroms .

Due to the intergrowth of the three components direct measurements were not obtained for the $\{100\}$ and $\{010\}$ planes. These were assigned such values that when they were combined with the above spectrometer measurements best agreement with the principal powder lines was obtained. These values together with the computed spacings for the principal planes are shown in column four, Table 1, and in Fig. 3. For smaller spacings there are so many possible lines that agreement between the observed and either calculated set is within the experimental limit.

AUTONOMOUS AND SINGULAR NODES

VICTOR GOLDSCHMIDT, *Heidelberg*.¹

By a *node* we mean the *projection-point* of a crystal face, as shown either on a gnomonic or stereographic diagram. The point represents the *face-normal*, and this in turn the vector, that is, the direction and intensity of the *force of attraction of the particle* (*Partikelattraktionskraft*). The point represents the face itself together with all its properties. The broad significance of the word node is of the greatest value to us (1, pp. 57–59) since it links the above conceptions into a single unity in which the most important properties of the crystal converge.

Nodes are designated by the letters: a, b, c, m, p, x , etc. The letter is the arbitrarily chosen proper name of the node; it represents at once the face, the projection-point, the face-normal and the vector, and includes all their properties.

We can distinguish between principal and subordinate, primary and derived, strong and weak nodes. As a vector, a node has direction and counter-direction, pole and counter-pole, plus and minus direction; as a face, it has face and counter-face. In the gnomonic diagram pole and counter-pole coincide.

A zone connects two nodes and at the intersection of two zones lies a node. Vectorially speaking the *zone-plane* is the field of force between two vectors (nodes). In the zone, derived nodes are developed according to the Law of Complication. Derived zones connect primary and subordinate nodes with differentiation of still other nodes according to the Law of Complication. The primary and the derived nodes and zones taken together constitute the *typical form-system* of the crystal species. This is completed by the addition of vicinal and accessory forms to give the *complete form-system* of the crystal species.

The *development of the form-system* (2) of a crystal species is its derivation from the *primary nodes*. The primary nodes from which the development proceeds are at the same time the *principal nodes*, namely, the most important nodes according to size and frequency, as shown by statistical methods.

In exceptional cases it is observed that a subordinate node, according to size and frequency, acts as a primary node by entering

¹ Appeared first in German: VICTOR GOLDSCHMIDT, *Autonome und singuläre Knoten*, *Cb. f. Min.*, 1930, A, pp. 209–219, Figs. 1–13. Translated into English, at Professor Goldschmidt's request, by M. A. Peacock, Vancouver, B. C.

actively and independently into the development of the form-system. In this case we have a weak (subordinate) primary node. In general, the conceptions of principal node and primary node are confluent, and the two can be interchanged without incurring error. With rare exceptions, principal nodes are at the same time primary nodes, and vice versa.

Only a small group of principal nodes controls the development of forms, twinning and regular intergrowths, cleavage, and other physical properties. This small group can be ascertained for each crystal species by a statistical study. The determination of this group of principal nodes is an important task which must be accomplished for each crystal species.

Examples: Calcite: principal nodes = $\dot{p}, b, c, \dot{\phi}', \delta$
 Orthoclase: " " = P, M, T
 Quartz: " " = r, ρ, b

The principal nodes determine the crystal system. We read off the elements, which characterize the crystal system, from the arrangement of the principal nodes in the gnomonic diagram. In doing this, it is immaterial which of the principal nodes we use.

Example: We obtain the same regular (cubic) elements from the octahedron as from the dodecahedron. We succeed in determining the crystal system of every well-developed crystal, as some of the principal nodes are always present.

We can distinguish six crystal systems, and define them as follows: A crystal system is the sum total (Inbegriff) of all crystal species with the same number of variable elements (3). We have the following cases:

	<i>Variable elements</i>
Regular system.....	0
Hexagonal and tetragonal systems.....	1
Rhombic system.....	2
Monoclinic system.....	3
Triclinic system.....	5

The elements of length $p_0q_0=1$ and the angular elements $\lambda, \mu, \nu=60^\circ, 90^\circ$ are constant.

Node and counter-node. In general, every face has its counter face, and thus direction and counter-direction of the (face) normal to the vector are equivalent; node=counter-node. But there are exceptions in which polar opposition exists between face and counter-face; direction and counter-direction, node and counter-

node are not equivalent. The counter-node then enters differently into the development of the form-system, sometimes not at all. When node and counter-node are equal, we speak of homopolarity; when unequal, of heteropolarity. In the latter case we distinguish between a positive and a negative end, and speak of an analogous and an antilogous (antilog) pole.

Example: In zinc blende the opposition between tetrahedron and counter-tetrahedron is strong; in diamond it is weak.

Analogy: The magnet has a positive and a negative end. If the contrast is strong, we speak of strong magnetism; if weak, of weak magnetism.

Polarity has no influence on the elements, and thus it has none on the crystal system but polarity assists in determining the division (1), namely, hemihedrism, tetartohedrism and hemimorphism.

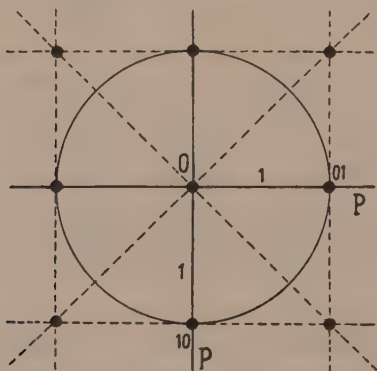


FIG. 1. REGULAR
24 symmetry fields plus
24 counter-fields.

DIVISION OF GNOMONIC FIELDS

By measurement we determine the crystal system and its elements; these imply a corresponding division into fields in the gnomonic diagram.

Note: We shall restrict ourselves at first to the gnomonic diagram, omitting other representations (stereographic, perspective projection-diagrams, etc.); we employ these when special requirements arise.

Note 1. In the *monoclinic* system we have two equally valid gnomonic normal diagrams:

1. M_1 with projection in the plane $[PQ]$ perpendicular to the prism zone (Fig. 5). We call this the *normal projection*, with the projection elements: $p_0'q_0'h=1$; $e'=e/h=\cot\mu$.

2. M_2 with projection in the plane $[P R] (\perp Q)$. We call this *projection on the symmetry plane* (0∞), with the projection elements: $p_0 r_0$ ($q_0 = h = 1$) μ .

Note 2. In the *rhombic* system we have three equally valid gnomonic diagrams:

R_1 in the plane $\infty 0$; R_2 in the plane 0∞ . R_3 in the plane 0 .

We call R_3 the *normal projection*; it is determined by the choice of the prism zone. $R_1 R_2$ are employed occasionally. $R_1 R_2 R_3$ together with the counter-faces $\underline{R_1} \underline{R_2} \underline{R_3}$ constitute the surface of the polar form.

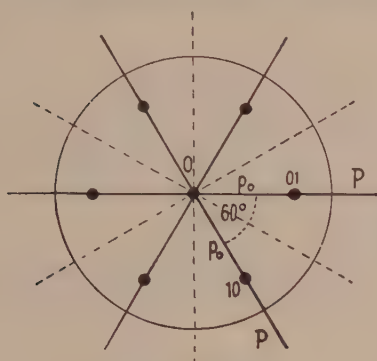


FIG. 2. HEXAGONAL
12 symmetry fields plus
12 counter-fields.

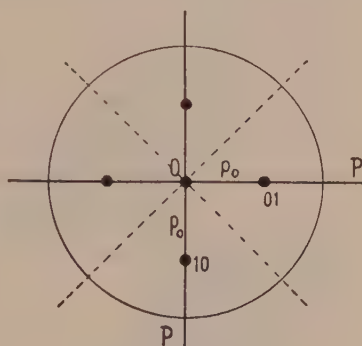


FIG. 3. TETRAGONAL
8 symmetry fields plus
8 counter-fields.

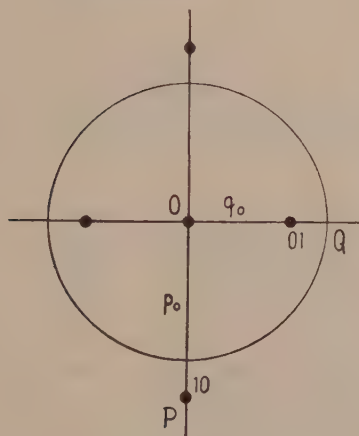


FIG. 4. RHOMBIC
4 symmetry fields plus
4 counter-fields.

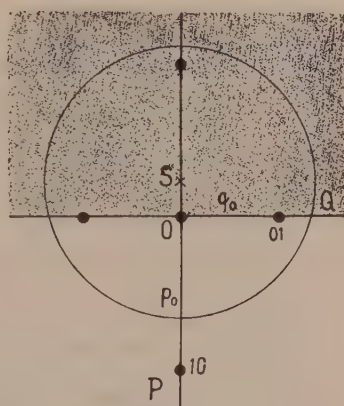


FIG. 5. MONOCLINIC (M_1)
2 pairs of symmetry fields plus
counter-fields.

Symmetry of the elements. Symmetry of the crystal system.
The elements of each crystal system show a characteristic sym-

metry in space as they do on the gnomonic diagram. We assume (until we have more information) that this symmetry is due to a symmetry in the arrangement of the component parts of the crystal-building particles, and in the forces of attraction of the particles.

By the symmetry of elements we understand, furthermore, equality of their lengths and angles.

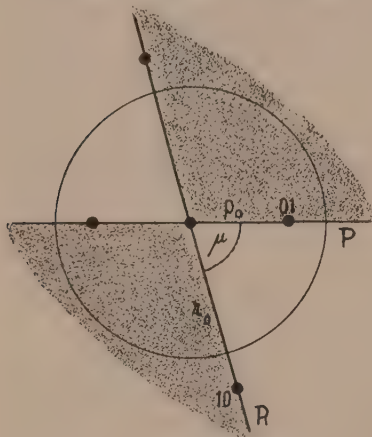


FIG. 6. MONOCLINIC (M_2)

2 pairs of symmetry fields plus counter-fields.

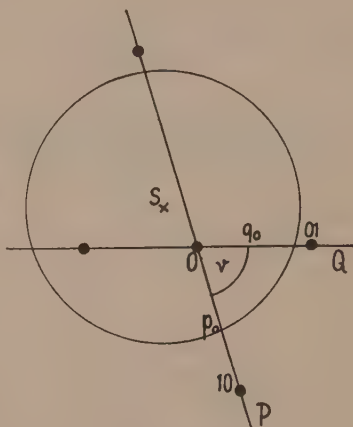


FIG. 7. TRICLINIC

4 unsymmetrical fields plus counter-fields.

The symmetry of the polar elements include $p_0 q_0 (r_0 = 1)$ λ , μ , ν . We have the following cases:

Regular: $p_0 = q_0 = r_0 = 1$; $\lambda = \mu = \nu = 90^\circ$.

Equal: all lengths and angles. Variables: none.

Hexagonal: $p_0 = q_0 \neq r_0 = 1$; $\lambda\mu = 90^\circ$, $\nu = 60^\circ$.

Equal: 2 lengths, 2 angles 90° . Variables: 1 length, 1 angle 60° .

Tetragonal: $p_0 = q_0 \neq r_0 = 1$; $\lambda = \mu = \nu = 90^\circ$.

Equal: 2 lengths, 3 angles 90° ; Variables: 1 length.

Rhombic: $p_0 \neq q_0 \neq r_0 = 1$; $\lambda = \mu = \nu = 90^\circ$.

Equal: 0 length, 3 angles 90° . Variables: 2 lengths.

Monoclinic: $p_0 \neq q_0 \neq r_0 = 1$; $\lambda\nu = 90^\circ$, $\mu < 90^\circ$.

Equal: 0 lengths, 2 angles 90° . Variables: 2 lengths, 1 angle.

Triclinic: $p_0 \neq q_0 \neq r_0 = 1$; $\lambda \neq \mu$, $\neq \nu \neq 90^\circ$.

Equal: 0 length, 0 angle. Variables: 2 lengths, 3 angles.

Symmetrical gnomonic fields, or briefly, **gnomonic symmetry**. The division into gnomonic fields (Figs. 1-7) shows that for each

crystal we have a definite symmetry of the fields. We distinguish between:

Reflection symmetry: two fields coincide by reflection in a meridian, and rotation symmetry: two fields coincide by rotation about a pole through 30, 45, 60, 90°.

Fields symmetrical by rotation are often also symmetrical by reflection, but not always. Here we consider both types as symmetrical.

Note 1. The symmetry of fields in the regular system does not appear fully in the gnomonic diagram; it does, however, in the projection on the polar form, the cube (Fig. 8). When we speak of symmetrical fields in the regular system, we mean the fields of the polar form.

Note 2: In all the crystal systems, the lower gnomonic plane has the same division into fields as the upper, with the same symmetry of fields.

Number of symmetrical fields: On the upper gnomonic plane we have the following cases:

	<i>Symmetrical fields</i>
Regular.....	24=12 pairs
Hexagonal.....	12=6 pairs
Tetragonal.....	8=4 pairs
Rhombic.....	4=2 pairs
Monoclinic.....	2=1 pairs
Triclinic.....	0=0 pairs

In the paper "*Über Kristallssysteme, deren Definition und Erkennung*," 1899 (3), five different definitions, *A, B, C, D, E*, were given for the crystal systems; of these *D, E*, appeared to be the best. They were:

Definition *D*: A crystal system includes all crystals with the same symmetry of elements.

Definition *E*: A crystal system includes all crystals with the same number of variable elements.

In addition to the above, we can add a new definition *F*.

Definition *F*: A crystal system includes all crystals with the same number of symmetrical gnomonic fields.

Definition *F* can accompany *D* and *E*, or be substituted for them; it has several advantages.

1. *F* gives precision to the symmetry better than *D*, and shows the way in which the crystal system is determined on the basis of measurement and projection.

2. The division into fields is the basis for the sub-divisions of the

crystal systems (1), namely, holohedrisism, hemihedrisism, tetartohedrisism and hemimorphisism.

Note. Several definitions of the same conception are not objectionable, especially when each definition can be reduced to the other. According to usage, one or the other may be preferred. When considering work of a morphological character, the morphological definition is preferable; when of an optical character, the optical. This is particularly true when the definition, taken rigorously, is only a characterization.

Example. A bird is recognized by its feathers or by its song; a crystal system, by the symmetry of the gnomonic fields or by the number of its variable elements.

Fields of the polar form. The polar form has the half edge-lengths p, q, r and the edge-angles λ, μ, ν . Figures 8-13 give the polar forms of the six crystal systems with the divisions into fields by axes and diagonals.

Symmetrical fields of the polar form. Here, also, we distinguish between reflection and rotation symmetry; reflection symmetry referring to a meridian, rotation symmetry to a pole. We have:

Regular:	3 equal square faces C .
Hexagonal:	1 hexagonal face C ; 3 rectangular faces A .
Tetragonal:	1 square face C ; 2 rectangular faces A .
Rhombic:	3 rectangular faces C, B, A .
Monoclinic:	2 rectangular faces C, A ; 1 parallelogram face B .
Triclinic:	3 parallelogram faces C, B, A .

Each face of a polar form has its division into fields (Figs. 8-13) which are either symmetrical or unsymmetrical. This division into fields is important in the study of the form-system of every crystal species. For our classification it suffices to divide the upper face of the polar form C into fields. Only in the regular system must we consider the three faces C of the polar form to obtain the 24 fields, of which only 8 have the same gnomonic shape, although we may call them all symmetrical. By symmetrical we mean those that are symmetrical on the polar form (cube).

EQUIVALENCE

Under equivalent formations (Gebilde) we would include fields, zones, *Züge*, and nodes. The conception of equivalence was first introduced in 1899 in the following manner. We read (1, pp. 60-61, *trans.*):

Let *equivalent* (*äquivalente, gleichwertige*), points be points of equal effect, as points of similar face position, of equal intensity, of equal relation to the form-development, of equal cohesion, of equal refractivity, of like position of the ray in the structure of the particle, and of equal atomic (molecular) position in the particle.

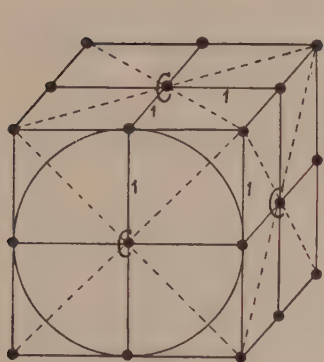


FIG. 8. REGULAR

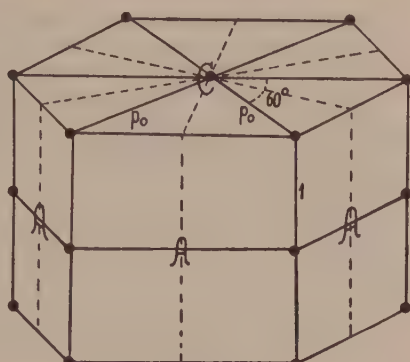


FIG. 9. HEXAGONAL



FIG. 10. TETRAGONAL

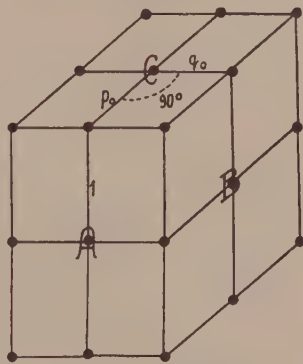


FIG. 11. RHOMBIC

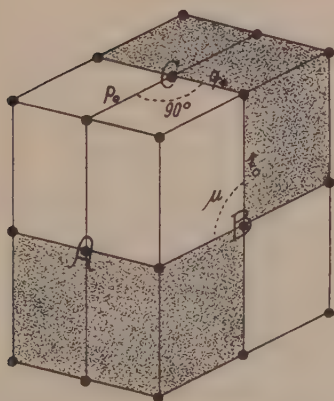


FIG. 12. MONOCLINIC

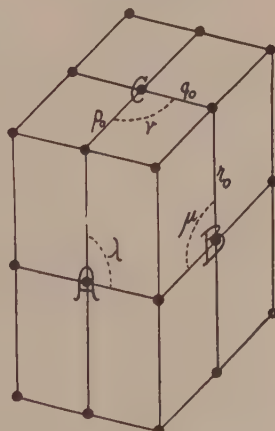


FIG. 13. TRICLINIC

All these properties are causally connected, so that equality with respect to one of them carries equality with respect to the others. Where this is not the case, equivalence must be specified with respect to a certain property.

Example: Crystallometrically equivalent points, *i.e.* equivalent with respect to position of the faces, are optically equivalent; but the reverse does not hold true.

Equivalent zones (Züge) are those that include equivalent points and equivalent zones connect equivalent nodes.

Let *equivalent fields* be fields of equal shape, bounded by equivalent points (nodes) and zones in the same succession.

In them there takes place at the same time the same processes of complication in the forming of faces, consequently the same distribution of points.

As equivalent fields are crystallometrically, physically and genetically equal in value, we may say: *equivalent fields are fields of equal effect bounded by zone-lines*. A field could also be bounded by lines other than zone-lines.

The Law of Equivalence. The repetition of equivalent points on one crystal is a peculiarity of the crystal. This we shall call the Law of Equivalence; it is the cause of symmetry. A point is, almost without exception, accompanied by one or more equivalents—crystallometrically up to 48 optically entire zones (*Züge*). The repetition of equivalent points causes the repetition of equivalent *Züge*, zones and fields.

The Law of the Complete Form (Gesamtform). The Law of Equivalence appears crystallometrically as the Law of the Complete Form. According to the law that like cause has like effect, faces appear at the same time on a crystal everywhere where the force relations are the same, that is at equivalent points. Therefore, faces do not appear singly but associated in groups. Such groups of associated faces we term a complete form, which we may define as follows: *A complete form (Gesamtform) is a group of associated faces, due to equivalence, and therefore occurring together.*

Division of the crystal systems according to equivalence of fields. We divide the fields, as we did above, according to the elements. We may now express the definition of the divisions so that it has crystallometric, and at the same time, physical and genetic significance. We can say:

Holohedrism is equivalence of all the fields.

Hemimorphism: Upper half of the crystal is not equivalent to the lower half.

Hemihedrism is equivalence of one-half of the fields.

Tetartohedrism is equivalence of one-fourth of the fields.

For the kinds of hemihedrism we have the following grouping:

- | | |
|---|--|
| | $F=C$, that is field and counter-field are equivalent. |
| A | $F \neq C$, that is field and counter-field are not equivalent. |
| | Equivalent fields alternating in quadrants, |
| B | Equivalent fields alternating in pairs, |
| | Equivalent fields alternating singly. |

On account of the context, it seemed proper to insert here what was said over thirty years ago (1899). To this I shall add: All

equivalent formations (Gebilde) are symmetrical, but symmetrical formations are not all equivalent.

AUTONOMOUS NODES

The conception of *autonomous* is to be considered as closely related to the term primary. The difference is as follows: primary implies that the development starts from the node; autonomous implies that the node plays an active, independent part in the development. Of the autonomous nodes of a crystal species, one group may, on occasion, initiate the development (that is may be primary); at another time it may be another group. The primary nodes determine the habit.

Example: In alum the octahedron (p) and the cube (c) are autonomous; but sometimes the development proceeds from the node p , and then p is primary and determines the habit; sometimes it proceeds from c . Thus p or c may be primary and determinative of the habit and development; both are autonomous.

Autonomous nodes are those making independent, active entry into the form development. Several autonomous nodes may be equivalent. According to their size, direction and symmetry, they determine both the crystal system and division, also the form development and elements of the crystal species.

Each autonomous node has its own peculiarity which is shown by the peculiar way in which each enters actively into the form development. This entry may be one-sided, as for example in quartz (1, p. 64).

The search for autonomous nodes and the study of their peculiarities is an important problem of crystal morphology.

Autonomous nodes and the *structure of the particle* are closely related. From the arrangement and peculiarity of autonomous nodes we may infer a peculiarity in the structure of the particle, and, even in the arrangement and peculiarity of the component parts of the particle.

A more detailed exposition is to be found in the author's publication: "Über Entwicklung der Kristallformen" (2). There the following hypothesis was introduced: The straight lines from the center of gravity of the particle to the centers of gravity of the individual components of mass (atoms, molecules) composing the particle, are preferred directions.² This rests on the hypothesis introduced in

² The context suggests that these "preferred directions" are also the directions given by the autonomous nodes.—*Translator's note.*

1886 (5, p. 6) which stated that every plane normal to an attraction force of the particle is crystallonomically a possible face.

Both hypotheses have been repeatedly strengthened and confirmed during the thirty years' development of crystal morphology, and could, therefore, be included in the laws. They open a way of penetrating into the structure of the particle with the help of morphology.

Autonomous nodes and symbols. The elements and the symbols of the single faces depend on the autonomous nodes, since the zones, in which the typical forms are developed according to the Law of Complication, extend from the autonomous nodes. With rare exceptions, autonomous nodes themselves can be expressed in simple symbols, and on this simplicity depends the simplicity of the symbols of the derived forms.

SINGULAR NODES

In addition to the autonomous principal nodes which determine the elements, and thereby the symbols, of the individual forms of a crystal species, and which themselves have simple symbols, autonomous nodes with complicated symbols occur in some crystal species. These we shall call singular nodes with the following definition:

Singular nodes are autonomous nodes with complicated symbols. Through zonal connection with other nodes, these singular nodes are accompanied by forms having very complicated symbols when referred to the elements of the crystal—so complicated that, in spite of their rational derivation, we hardly like to call them rational.

Series of forms derived from singular nodes are simple and intelligible only when referred to the appropriate single nodes as points of origin of the form development in the zones.

Such a case is found in calaverite in which occurs a pair of singular nodes C with the symbol $C = -3/29 \cdot 5/29 (\bar{3}.5.29)$; these enter essentially into the development of the form-system by acting as end-nodes in the zonal development. Details will be given in a forthcoming publication on calaverite from Cripple Creek by V. GOLDSCHMIDT, C. PALACHE AND M. PEACOCK. With the help of the singular nodes C it was possible to understand and derive the form-system of calaverite.

The case is not an isolated one. In wolfsbergite (guejarite) the

form $p = \frac{7}{6} \cdot \frac{3}{2}$ (796) which, with complicated symbol, enters autonomously into the form development, is to be regarded as a singular node (6, p. 295).

It is to be expected that singular nodes are not rare. Their determination and the study of their peculiarity and their mode of action might explain some appearances in the development of the forms of crystals hitherto not understood or not observed.

Singular nodes and structures of the particle. Like all autonomous modes, singular nodes are related to the structure of the particle, and may be called upon to give information on this structure. This gives them particular importance. Every singular node corresponds to a singular property in the structure of the particle.

REFERENCES

- (1) V. GOLDSCHMIDT: Über Abteilungen der Kristallsysteme, *Zs. f. Krist.*, **32**, pp. 49-65, 1899.
- (2) ———— Über Entwicklung der Kristallformen, *ibid*, **28**, 1-35, 414-451, 1897.
- (3) ———— Über Kristallsysteme, deren Definition und Erkennung, *ibid*, **31**, pp. 135-159, 1899.
- (4) ———— Über Verknüpfung der Kristallpartikel, *ibid*, **29**, pp. 38-53, 1898.
- (5) ———— *Index der Kristallformen*, **1**, 1886.
- (6) E. ERNEST: Die Kristallformen des Wolfsbergits, *N. Jb. f. Min., Bl. Bd. LXI, A*, pp. 275-315, 1928.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, November 6, 1930.

A stated meeting of the Philadelphia Mineralogical Society was held on the above date, Mr. Toothaker presiding. There was an attendance of sixty-five persons. Upon favorable recommendation of the council, Mr. George Wilkes was elected a junior member. A committee was appointed by the chair to formulate resolutions on the death of Dr. J. B. S. Egee, one of the oldest members of the society.

Mr. Lester W. Strock spoke of a trip to "Northern Ontario and the Canadian Rockies." Mineral localities visited included Bedford, New York; Portland, Connecticut; Westfield, Massachusetts; Chester, Vermont; Grenville, Perkins Mills, and Cantley, Quebec; Timmons and various mines near Kirkland Lake, Cobalt, Ontario; and Noranda in western Quebec. Common ore minerals were obtained at these localities, but no fine crystallized specimens. The speaker concluded his remarks with an account of a trip to the Columbian icefield. A series of lantern slides was shown. A vote of thanks was given the speaker.

LESTER W. STROCK, *Secretary*

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, December 4, 1930.

A stated meeting of the Philadelphia Mineralogical Society was held on the above date with the president, Mr. Toothaker, in the chair. There was an attendance of seventy-one persons. Upon favorable recommendation of the council Messrs. William Emtage, Edward Healey, and L. A. Morgan were elected members, and Messrs. George Johnson, Howell Joblins, William Hackett, and James McNair, junior members.

As the subject of the evening, Mr. Edmund Cienkowski spoke on the theme "Southwest by Motor," which was descriptive of a trip across the continent in search of mineral specimens, in which the speaker was accompanied by Messrs. Fred Reinitz, and Edward K. Graham. Many lantern slides were shown, and specimens of the following minerals were exhibited: green, purple, and yellow fluorite from Rosiclare, Illinois; calcite, sphalerite, galena, marcasite, chalcopyrite, and dolomite from the Joplin district; quartz from Hot Springs, Arkansas; wulfenite from the Organ Mountains, and malachite from Bisbee, Arizona; vanadinite from the old Yuma mine near Tucson, Arizona; and also from the Apache mine near Globe; tourmaline from Pala, California; some meteoric iron from Canyon Diablo, Arizona; silicified wood from the Petrified Forest, Arizona; and smithsonite from Kelly, New Mexico. A vote of thanks was given the speaker.

LESTER W. STROCK, *Secretary*

NEW YORK MINERALOGICAL CLUB

The regular meeting of the New York Mineralogical Club was held at the American Museum of Natural History, on the evening of December 17, 1930, with the president, Mr. Allen, in the chair. The following were elected to membership: Mrs. J. R. Algor, Mr. H. E. Engel, Mr. Joseph Sternberg and Mr. Stanley Harzfeld. Mrs. Richard Durkee of New York City was proposed for membership, and her name referred to the membership committee.

Mr. J. C. Boyle, the speaker of the evening, spoke on "*Mineral Collecting in Ontario and Quebec.*" The localities visited are located in the eastern part of Quebec and Ontario. Specimens were secured from Thetford, Quebec, and from Cantley, Bancroft, Hybla, and Wilberforce, Ontario. The nature of the region covered was described, and the lecture illustrated by means of interesting lantern slides taken at the various localities. A selection of the minerals collected was also exhibited. The speaker received a rising vote of thanks.

After the address, members were invited to present problems or matters of special interest. Messrs. Hoadley and Grenzig responded by exhibiting specimens of an unusual nature.

The plan has recently been inaugurated to invite the members to gather and have dinner together at the Hotel Endicott, not far from the Museum, before the regular meetings. Those who have attended these informal dinners have been greatly pleased with the innovation, and will be glad to have others join them.

JAMES F. MORTON, *Secretary*

NEWARK MINERALOGICAL SOCIETY

At the 115th regular meeting held November 2, 1930, at the Newark Technical School, the following officers and trustees for the year 1930-1931 were elected:

President—John A. Grenzig

Vice-President—George E. Carpenter

Secretary—Herbert L. Thowless

Treasurer—Herman M. Lehman

Charles W. Hoadley was re-elected to the Board of Trustees for a three year term. The Board now consists of four officers, Charles W. Hoadley, Paul Walther and Mrs. Victor C. Gilbert.

HERBERT L. THOWLESS, *Secretary*

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

MINERALOGICAL SOCIETY, November 4.—*Anniversary Meeting*.—Sir John S. Flett, president, in the chair. MR. ARTHUR RUSSELL: *An account of British mineral collectors and dealers in the 17th, 18th and 19th centuries*. A first installment of a series of short biographies dealing with:—Nehemiah Grew, F. R. S., (1641-1712); William Borlase, F. R. S., (1696-1772); Rudolf Eric Raspe, (1737-1794); and Philip Rashleigh, F. R. S., (1729-1811).

MR. M. H. HEY: *On Cupriferous melanterite from the Skouriotissa mine, Cyprus*. A crystallographic study of a well-crystallized specimen from an ancient working (perhaps Roman) in the Skouriotissa mine, revealed a very peculiar habit tabular to $b(010)$, and the presence of the new forms $x(161)$, $y(2\bar{3}1)$, $g(\bar{1}12)$, $q(\bar{1}02)$, and $\beta(150)$. A partial analysis shows the presence of 7.7% $\text{CuSO}_4 \cdot 7\text{H}_2\text{O}$.

DR. C. E. TILLEY: *On the dolerite-chalk contact zone of Scawt Hill, Co. Antrim*. The production of basic alkali rocks by the assimilation of limestone by basaltic magna. (With chemical analyses by Dr. H. F. Harwood): Assimilation of limestone at the contact of a dolerite intrusion with the chalk at Scawt Hill gives rise to a hybrid zone built up of pyroxene-rich rocks (pyroxenites), titanaugite-melilite rocks, and basic rock-types bearing nepheline (theralite and nepheline-dolerite assemblages). The segregation of a basic alkali residuum is the complementary process in the precipitation of magnesian rich pyroxene in the pyroxenites. Plagioclase is resorbed and gives place to a titaniferous lime-augite rich in alumina, melilite and nepheline, while perovskite, aegirine, and wollastonite are other products in the hybrid zone.

DR. FRANK SMITHSON: *A simple method of observing the magnetic properties of mineral grains*. The tests are made with softened steel needles attached to the poles of a horse-shoe magnet, a strong field being obtained when the points are 1 mm. or so apart. The attraction is observed under the microscope.

MR. M. H. HEY: *On studies of the zeolites. Part I*. General review. A short review of the general properties of the zeolites, with some suggestions on the interpretation of the available data, and a comparison of the zeolites with the clays, ultramarines, permutites, and 'artificial zeolites.'

W. CAMPBELL SMITH, *General Secretary*

NEW MINERAL NAMES

Stainerite

A. SCHOEF AND V. CUVELIER: Sur la stainerite (Un hydroxyde cobaltique) Nouveau minéral. [Stainerite (cobaltic hydroxide) a new mineral]. *Bull. Soc. Bel. Geol.*, **39**, pp. 74-82, 1930.

NAME: In honor of Prof. Xavier Stainer of the University of Gand.

CHEMICAL PROPERTIES: A hydrated cobaltic oxide, $\text{Co}_2\text{O}_3 \cdot \text{H}_2\text{O}$. Analysis (mean of several): SiO_2 2.67, CuO 2.68, Co_2O_3 68.72, Fe_2O_3 9.45, Al_2O_3 6.87, H_2O 10.15, Total 100.54. (Malachite, hematite, kaolinite and quartz present as impurities). Easily soluble in hydrochloric acid to a green solution with evolution of chlorine.

PHYSICAL AND OPTICAL PROPERTIES: Color black, streak black. Opaque. Color on polished section white, slightly grayish, also gray, slightly brownish. Birefringent. $H.=4-5$. $\text{Sp. Gr.}=4.317$ at 17°C .

OCCURRENCE: Found in large quantities as a gossan at Mindingi, Katanga, as fine granular masses or concentrically banded.

DISCUSSION: The mineral is granular and crystalline, not colloidal and an X-ray examination (by W. F. deJong) shows it to be similar to goethite in structure.

W. W. FOSHAG

Fersmannite

A. LABUNCOV: La fersmannite—un nouveau minéral des Monts Chibines. (Fersmannite—a new mineral from the Chibines Mts.). *Comp. Rend. l'Acad. Sci. URSS*, **1929**. A. 297-301. (In Russian. Abst. in *Neues Jahrbuch Min. Geol. und Paleon.*, Referate, **1930**, p. 125).

NAME: In honor of Dr. A. Fersmann, eminent Russian mineralogist, leader of the expeditions to the Chibina Tundras.

CHEMICAL PROPERTIES: A fluo-titano silicate of soda and lime. Formula: $2\text{Na}_2(\text{O}, \text{F}_2) \cdot 4\text{CaO} \cdot 4\text{TiO}_2 \cdot 3\text{SiO}_2$. Analysis (1) by Wrevskaja and (2) by Wlodavetz: SiO_2 23.42-22.30; TiO_2 37.95-37.34; Fe_2O_3 0.34-0.45; CaO 25.15-26.16; FeO 1.36-0.30; MnO tr.—0.25; MgO tr—0.08; Na_2O 8.10-9.88; K_2O 0.37 — tr; H_2O 0.84-1.26; F 3.09-3.61; Total 100.62-101.63.

CRYSTALLOGRAPHIC PROPERTIES: Monoclinic, holohedral with pseudotetragonal habit. $a:b:c=0.99113:1:0.99613$; $\beta=97^\circ 16'$. Forms (001), (223), ($\bar{1}12$); also (110), (223), (553).

PHYSICAL AND OPTICAL PROPERTIES: Color brown, luster vitreous. $H.=5.5$. $\text{Sp. Gr.}=3.44$.

Biaxial, negative, $2V=0-7^\circ$. Plane of the optic axes parallel to the plane of symmetry. Bx_2 almost perpendicular to (001). $\alpha=1.886$, $\beta=1.930$, $\gamma=1.939$, $\gamma-\alpha=0.053$.

OCCURRENCE: Found in Aegirine-nephelite feldspar veins that cut the nepheline syenite with lamprophyllite, apatite and pectolite.

W. F. F.

Correction

On pages 564 and 565 of the December issue of THE AMERICAN MINERALOGIST the plate numbers should be reversed: Plate VII should be Plate VI, and Plate VI should be Plate VII.